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Developing a Policy Roadmap for Smart Cities and the Future Internet

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Abstract: The FIREBALL project explores the impact of the Future Internet technologies on Smart Cities. This paper proposes a smart cities innovation roadmap framework and recommendations for urban development enabled by future Internet technologies. The roadmap framework aims to support the innovation policies and strategies of cities towards becoming "smart". The innovation roadmap is based on a system of innovation perspective, combining views on regimes and niches of novel solutions. These policies concentrate primarily on the management of fundamental layers for achieving a spatial intelligence of cities embedded on future Internet technologies and user-driven innovation ecosystems.

1. Introduction: The Turn to Smart City Strategies

Cities and urban areas are complex social ecosystems, where ensuring sustainable development and quality of life are important concerns. In such urban environments, citizens, companies and local governments experience specific needs and demands regarding key themes such as sustainable development, business creation and employment, healthcare, education, energy and the environment, safety, and public services. Increasingly, these domains are enabled and facilitated by broadband networks, Internet-based applications and open platforms. At the same time, the current economic climate forces many cities to cut budgets and set priorities and consequently cities are facing tough challenges to maintain and upgrade ICT infrastructures and innovation policies. This paper explains how the creation of a common roadmap for urban innovation and economic development as enabled by the Future Internet, supported by all stakeholders and addressing agreed priorities, helps finding consensus on common longer term objectives.

Future Internet research programs are based on the belief that the current Internet has reached his limits [1]. However, there are still open questions such as articulating the various relevant research areas, methods and tools from which new technologies, applications and services will emerge as well as the feasibility to combine technology push and application pull approaches. For research on the Future Internet to benefit not only research communities but also SMEs, citizens and cities it is important to integrate the research and experimentation perspective with the concept of user driven open innovation.

The Smart Cities concept, endorsed by the Eurocities community (www.eurocities.eu), is connected to notions of global competiveness, sustainability, empowerment and quality of life, enabled by broadband networks and modern ICTs [3]. Its implementation requires the development of migration paths regarding Internet infrastructures, testbed facilities, networked applications, and stakeholder partnerships. Informed by technological opportunities, future development strategies and cost-benefit assessments, cities should

develop priorities regarding socially and economically desirable applications, based on strategic objectives regarding economic and social development of city areas. Resources contributed by different stakeholders that might be shared by stakeholders to realize smart city strategies include Living Labs facilities, Future Internet research and testing facilities, cloud computing, as well as web-based methodologies, software tools and managed user communities [1].

The Fireball project (www.fireball4smartcities.eu) explores how cities and urban areas represent a critical mass when it comes to shaping the demand for advanced Internet-based services in large-scale testing and validation [3]. Shaping this demand informs ongoing research, experimentation and deployment activities related to Future Internet testbeds, and helps establishing a dialogue between the different communities involved in the development of the future Internet and user-driven environments, to form partnerships and assess social and economic benefits and discovery of migration paths at early stages. Development of a roadmap for smart cities will strongly contribute to establishing this dialogue.

2. Methodology

The methodology to underpin the effects of future Internet technologies on smart cities is based on a mixture of research of literature, cases studies on experimental facilities and discussions within the Fireball community of cities, companies and research institutes. The corpus of literature we are taking into account includes a variety of sources such as, the EU FP7 research on future Internet technologies, future media Internet, future media networks, experimental facilities of FIRE, and research on smart cities from the Competitiveness and Innovation Programme; OECD reports and governmental papers on the future of the Internet economy and strategic policy directions; large companies research programmes in the field of intelligent and smart cities; reports by consulting groups on emerging technology trends; recent Gartner surveys (2009 and 2010) on Emerging Technologies which illustrate different societal expectations, interest about and use of technologies; foresight exercises about the future of cities presented by academic institutions and the Institute for the Future.

The above foresight estimations and experiences drive the Smart Cities innovation roadmap we have elaborated. The roadmap methodology itself is based on four key questions: (1) what is changing in the domain of smart cities and future Internet research (FIRE); (2) what is the future vision for smart cities based on FIRE scenarios; (3) what are the challenges and gaps to be addressed for realizing the vision; (4) what are the niches of novel solutions to the envisaged gaps and challenges. The innovation roadmap methodology is based on [4] and considers four dimensions of upcoming trends: technological changes, business changes, policy changes, and societal changes. In elaborating the roadmap, we focus in particular on developments and impact of three main Internet-based technologies: cloud computing; real-world user interfaces of sensors, tags and RFIDs; and the semantic web. The aim is to assess the expected effects of these technologies on smart city solutions and operations, and the resulting changes on informational and cognitive processes of information collection and processing, real-time alert, learning, collective intelligence and problem solving, which characterize smart cities.

3. Technologies for Smart Cities

The Future Internet domain landscape comprises a great diversity of research streams and related topics for designing alternatives for the Internet of tomorrow. For example, the Internet of Things (IoT) is considered as a major research and innovation stream leading to plenty opportunities for new services by interconnecting physical and virtual worlds with a

huge amount of electronic devices distributed in houses, vehicles, streets, buildings and many other public environments. Hence, a massive amount of data will be flowing over the Internet that should not decrease the overall service performance and satisfaction. In [5] it is proposed to examine the four key components of a real time control system: entity to be controlled in an environment characterized by uncertainty; sensors able to acquire information about the entity's state in real-time; intelligence capable of evaluating system performance against desired outcomes; physical actuators able to act upon the system to realize the control strategy. This perspective corresponds to a new technology paradigm of "embedded spatial intelligence". The Institute for the Future [2], [9] has also identified some major trends of the future Internet technologies on smart cities, which emerge, among others, from cloud computing, smart sensors and devices, and open data.

3.1 Cloud Computing and Smart Cities

Cloud computing is based on several technology advances related to high-speed networks, virtualisation, and standardisation of platforms and applications. However, "cloud computing is a new way of delivering computing resources, not a new technology" [6], providing Internet delivered computer services and a series of new business models of outsourcing. The US National Institute for Standards and Technology offers a stylized description of cloud computing as composed of five essential characteristics (on-demand self service, ubiquitous network access, metered use, elasticity, and resource pooling), three service models (software as a service - SaaS, platform as a service - PaaS, and infrastructure as a service - IaaS), and four deployment modes (private, community, public and hybrid clouds) [7].

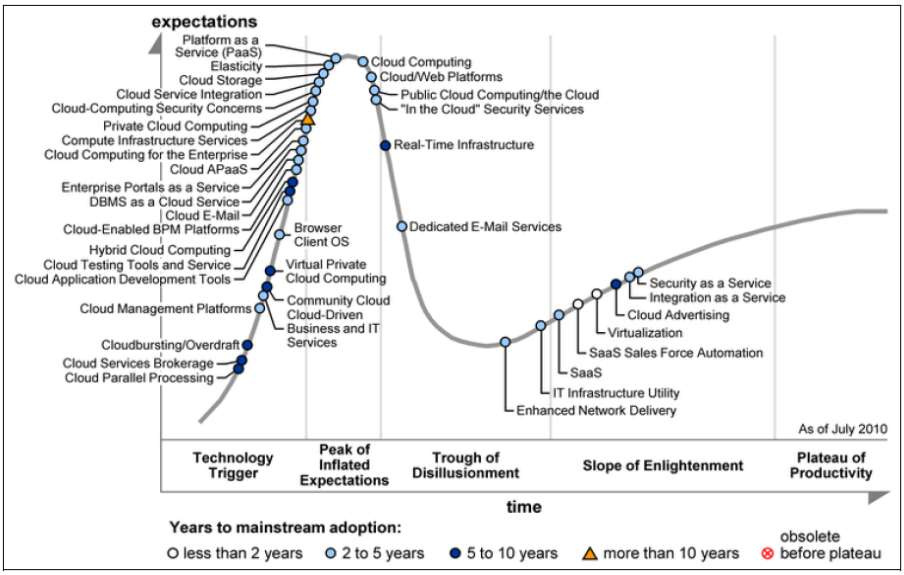

Figure 1. Gartner Hype of Cloud Computing [8]

Foresight estimations about developments in cloud computing is given by the Gartner Hype Cycle for Cloud Computing [8], which is positioning 38 technologies of this field at different stages of the Hype Cycle. In this type of analysis, each Hype Cycle is composed of five stages representing the typical progression of an emerging technology: (1) "Technology Trigger" or technology breakthrough and product launch that generate significant interest of the press, (2) "Peak of Inflated Expectations" the phase of over-enthusiasm and unrealistic expectations, (3) "Trough of Disillusionment" of reduced press interest because technologies fail to meet expectations and quickly become unfashionable, (4) "Slope of Enlightenment" with experimentations about the benefits and practical application of the technology, and (5) "Plateau of Productivity" in which the benefits of

technologies become widely demonstrated and accepted. Expectations about cloud computing are very high. Most technologies, however, are at the "technology trigger" stage, and cloud computing overall is at the peak of expectations; a few solutions are at experimentation stage and none at the stage of demonstrated results. The time frame for these solutions is from 2 to 10 years, and only virtualisation and software-as-a-service are closer to mainstream adoption.

Cloud computing and its impact on smart city solutions has been discussed in two forecast publications for 2020 [2], [9]. While in the short-term, cloud computing will be delivered by large commercial clouds, government G-clouds are promising models for (larger) cities, creating urban clouds that reduce IT costs, and providing platforms for small business applications and e-services. Cloud computing is opening also new possibilities in virtualisation of physical spaces and substitution by digital ones. Already because of the global 2009 crisis many activities and networks, from R&D to markets, go virtual allowing companies and organisations to maintain operations in times of austerity, gaining flexibility and lowering fixed costs. It sustains new growth sectors of cities, which are now moving from manufacturing to services in the framework of a wider movement from products to services, as material and intangible infrastructures start being provided by the cloud.

Extremely important is the expected standardisation of smart city systems, platforms, and applications, which is necessary to provide on-demand self services. Standardisation will accelerate technology diffusion and learning curves as city administrations and their IT departments will become aware of proven solutions for the main districts and sectors of the city. We should expect a standardisation of platforms and applications in about 20 different domains of cities, related to typical city districts (CBD, manufacturing, housing, education), city utilities (transport, energy, water, broadband), and city management (administration, democracy, planning). Collaborative innovation ecosystems might emerge in these areas.

3.2 Real-World User Interfaces, Sensors, RFID and Smart Cities

Internet-of-Things including sensor networks and RFID is another important emerging strand. These technologies can overcome the fragmented market and island solutions of smart city applications and provide generic solutions to all cities. Examples of generic architecture include networked RFID tags (passive and active tags, mobile devices), sensor networks (multimodal sensors and actuators, built-in intelligent agents), and connected objects such as distributed intelligent systems, intelligent objects and biometrics [10]. A new round of applications, such as location aware applications, speech recognition, Internet micro payment systems, and mobile application stores, which are close to mainstream market adoption, may offer a wide range of services on embedded system into the physical space of cities. Augmented reality is also a hot topic in the sphere of mobile devices and smart phones, enabling a next generation location-aware applications and services [8].

While the future uses of IoT technologies that will bridge the physical and virtual worlds are still largely a matter for speculation, there are estimations that they will bring significant economic benefits. The OECD policy guidance encourages research on economic and social impacts and foster business R&D encouraging technological neutrality, open global standards, and harmonization of frequency bands [11].

Embedded networks of sensors and devices into the physical space of cities are expected to enable a new type of spatial intelligence, advancing further the capabilities created by web 2.0 applications, social media and crowdsourcing. A real-time spatial intelligence having a direct impact on the services that cities offer to their citizens. The concept of spatial intelligence of cities refers to mechanisms that make a city intelligent or smart and allows unifying those of "intelligent city" and "smart city" under a common field of study focusing on their underlying informational and cognitive processes

(http://en.wikipedia.org/wiki/Spatial_intelligence_of_cities). Internet of Things brings us closer to the way William Mitchell [12] has described the intelligence of cities as residing in "the increasingly effective combination of digital telecommunication networks (the nerves), ubiquitously embedded intelligence (the brains), sensors and tags (the sensory organs), and software (the knowledge and cognitive competence)". Collective intelligence and social media has been a major driver of spatial intelligence of cities. Social media have offered the technology layer for organizing collective intelligence, with crowdsourcing platforms, mashups, web-collaboration, and other means of participatory problem-solving. Now, the turn to embedded systems highlight another route of spatial intelligence based on location accurate and real-time information. Smart cities with instrumentation and interconnection of mobile devices and sensors can collect and analyse data and improve the ability to forecast and manage urban flows, thus push city intelligence forward [13].

For this type of embedded spatial intelligence important is the development of Urban IoT platforms offering a common framework for ambient sensor networks as intelligent information infrastructure under universal ubiquitous sensor network architecture [14].

3.3 Semantic Web, Linked Data, Ontologies and Smart Cities

The OVUM report on smart cities [15] considers cloud computing and the IoT as fundamental layers of ubiquitous connectivity on which stands a layer of open public data and advanced analytics for fast-based decisions. The open standards trends have expended to government data and many agencies are providing access to datasets stimulating the creation of applications for information retrieval and decision making. Open data from various sources, government, sensors, citizens and businesses, offer opportunities for advanced analytics and intelligence to detect patterns, generate alerts, visualise information and predict trends.

In data-driven decisions, techniques for forecasting and predictive analytics are well established in many domains. What is relatively new is the semantic meaning provided by ontologies, like the Good-Relations annotator tool for creating rich RDF meta-data describing products or services and the introduction of HTML5. The cloud will offer additional functionalities for linked data as any object will be related to objects contained in the cloud. The semantic web is expected to breaks down barriers, merging data from different sources and presenting it in meaningful way. Social media based collaboration and collective intelligence can reach a higher level of efficiency and information accuracy. Future media research and technologies offer a series of solutions that might work in parallel to Internet of Things and embedded systems providing new opportunities for content management. Media Internet technologies is at the crossroads of digital multimedia content and Internet technologies, which encompasses media being delivered through Internet networking technologies, and media being generated, consumed, shared and experienced on the web. Technologies enabled by the functionalities of the Future Internet Media, such as content and context fusion, immersive multi-sensory environments, location-based content dependent on user location and context, augmented reality applications, open and federated platforms for content storage and distribution will provide the ground for new e-services within the ecosystems of cities.

Engagement of users and user-driven innovation are important precondition for success. The Web 2.0 era has pushed cities to consider the Internet (including mobiles) as a more participative tool for engaging citizens and tourists. Many initiatives were launched by cities. It already looks like an example of several cities based Living Labs for investigating and anticipating how digital technologies will change the way people live in the city and their implications at the urban dynamics.

Altogether, Future Internet, Living Lab and Smart City form an intelligent innovation ecosystem comprising users/citizens, ICT companies, research scientists and policy makers. In this ecosystem, while the Future Internet represents the technology push, Smart Cities represent the application pull and Living Labs form the exploratory and participative playground in between the FI technology and Smart Cities' applications. In contrast with a testbed, a Living lab constitutes a 4P (Public, Private and People Partnership) ecosystem that provide opportunities to users/citizens to co-create innovative scenarios based on technology platforms such as FI technology environments involving large enterprises and SMEs as well as academia from different disciplines. It appears that Future Internet testbeds could be enabling the co-creation of innovative scenarios by users/citizens contributing with their own content or building new applications that mash-up city open data.

4. Conclusions & Policy Recommendations

The above brief account on future Internet technologies and expected impact on cities allows defining an innovation roadmap towards smart cities. Cities are increasingly aware of the concept of "smart city" and actively developing strategies towards the goal of becoming "smart" and manage more efficiently city resources and addressing development and inclusion challenges. Part of the development towards smart cities is the co-creation / crowdsourcing paradigm, people-led testing and implementation of technologies and ICT-based applications in sectors such as health and assisted living, participative government, energy management, and new work environments.

The roadmap summarized here is based on a two-dimensional mapping of layers and time periods. The vertical dimension considers the following layers: technological change, business change, policy change and social change. The time dimension includes the short term, mid-term and longer term developments. In order to enhance the policy relevance of the roadmapping approach, we focus on the systemic character of innovations related to smart cities, which require concurrent processes of socioeconomic and technological change. To provide guidelines to this process, the roadmapping approach draws from systemic change literature taking into account several characteristics of systemic change which relate to the transformation towards smart cities, e.g. regimes, barriers, transitions, and niches of novel solutions.

The innovation roadmap presented on Table 1 highlights a series of themes at the intersection of future Internet technologies and smart cities. Recurrently, at multiple sections of the roadmap appear the transition to the cloud, smart city pilots, and city-wide open platforms of embedded systems. These areas are of primary importance for city authorities all over the world that are deploying strategies for smart cities, e-infrastructure and e-services to address the contemporary challenges of competitiveness and sustainable development. Thus, the roadmap allows formulating some policy recommendations to city authorities for mastering the new interdisciplinary planning for intelligent / smart cities and the interlinked layers of digital technology, people-driven innovation ecosystems, urban activities and infrastructure.

TRANSITION TO CLOUD: Policy white papers about the transition to the cloud provide valuable guidance to city authorities because these technologies are still evolving and have not yet fully addressed the issues of services standardisation, security, and privacy. The recommendation is for streams of consultation work, providing public agencies with guidance and documentation, cost and benefit analysis, development of services in less important areas initially, and then go on full deployment of new cloud-based services, and eventually the creation of G-city clouds. The recent report of Australian government [6] offers a global scan of public policies and programs addressing the transition to cloud computing in the US, UK, EU, Canada, and Japan. City authorities should also become aware that IoT solutions will increase dramatically the demand for broadband connections

at the transition from connecting people to connecting things. Network interoperability and merging of network and media technologies, as well as mobile to mobile communication (M2M), will be necessary to cover the broadband demand in the public space of cities.

Table 1: An Innovation Roadmap Toward Smart Cities

REGIME	***Short term (2014)***	***Medium term (2017)***	***Long term (2022)***
Technological change *(Dominant designs, emerging technologies, interoperability)*	-CLOUD: Virtualisation -CLOUD: IaaS for smart cities	-CLOUD: Web platform -CLOUD: SaaS for smart cities - Content-context fusion	-CLOUD: PaaS for smart cities -CLOUD: Service integration
	-IoT: RFID -IoT: Speech recognition -IoT: Open data apps [6], [8]	-IoT: Multimodal sensors -IoT: Location aware apps, [5], [6], [8]	-IoT: Urban IoT platforms -IoT: Cloud based ontologies -Content-centric networks [2], [9], [14], [16]
Industrial change *(Networks of technology developers, lobbying, standardisation)*	-CLOUD: Large companies clouds, Google, MS, Amazon global clouds	-CLOUD: Large cities clouds	-CLOUD: Standardisation of smart city applications / services
	-IoT: Sensors into utilities and energy networks [6], [8]	-IoT: Alliances of large companies and major cities [2], [6]	-IoT: Large scale applications [2], [3], [6]
Social change *(Behaviour, routines, values, preferences, demand, end-users)*	-CLOUD: Reduction of IT costs	-CLOUD: Security issues raised -CLOUD: Disaster management addressed	-CLOUD: Continuity of service -CLOUD: Learning curve
	- IoT: Experimental facilities -IoT: A few city pilots [6], [15]	-IoT: Multiple city pilots [9]	-IoT: Large scale demand for sensor-based city infrastructure [9], [15]
Policy change *(Regulations, economic instruments, governance, agreements)*	-CLOUD: Transition white papers -CLOUD: Preparing to the cloud	-CLOUD: Pilots at city levels -CLOUD: Legal and regulatory reform	-CLOUD: Whole smart cities on the Cloud [11], [15]
	-IoT: Preparing to the IoT [6], [11]	-IoT: Regulations and procurement [6], [9], [11]	
NICHES of novelties	***Short term (2014)***	***Medium term (2017)***	***Long term (2022)***
Technological change	-CLOUD: SaaS -CLOUD: IaaS	-CLOUD: PaaS	
	-IoT: Experimental facilities -IoT: Open / linked data [9]	-IoT: M2M in city environments [2], [9], [15]	
Industrial change	-CLOUD: Private and hybrid clouds -CLOUD: Hosting of G city services	-CLOUD: SaaS and PaaS in the main domains of cities	
	-IoT: IPv6 and HTML5 [6], [11], [15]	-IoT: Smart gird / smart meters in cities [3], [15]	
Social change	-CLOUD: Pilot city applications in city utilities, districts, and gov.	-CLOUD: Large scale demand of smart city applications and services	
	-IoT: Sensors for city environment alert [6], [8], [15]	-IoT: Embedded city intelligence proof of concept [6], [9], [15]	-IoT: Extended demand for sensor over city networks [11]
Policy change	-CLOUD: Government roadmaps to G services -CLOUD: US reform of IT management	-CLOUD: Standards development and adoption	
	-IoT: China encouraging technologies for IoT [6], [9], [11]	-IoT: FP8 IoT PPP -IoT: Harmonisation of frequency bands [6], [10]	

SMART CITY PILOTS: In developing smart city solutions, city authorities must be aware of existing methods for involving the users, which are abundantly described in the literature, such as the Lead User, User Driven Innovation, User Centred Design and User Created Content, and User Co-Creation perspectives. The existence of a new technology stack of "cloud-IoT-linked data" does not automatically guarantee the development of new services based by these technologies. The recommendation is to adopt Living Lab, Open Innovation, and Web 2.0 product development perspectives, which promote a more proactive role of end users and citizens in services innovation, assuring coordination between technology offer by vendors and services demand by citizens and cities.

URBAN IoT PLATFORMS: Future Internet technology is a driver for new infrastructure, platforms and solutions for smart cities. Multimodal sensors, extended networks of sensors over all city infrastructures, embedded user interfaces, mobile devices, and M2M communication will enable location-aware services, real-time response, and eventually forecasting. However this technology layer doesn't assure *per se* a higher intelligence and problem solving capability unless integrated into a wider architecture of "embedded spatial intelligence" involving more adequate practices and behaviour on behalf of citizens. The recommendation is for integrated solutions involving communities of citizens, IoT platforms, and services targeted at the problems of different city districts, sectors, and utilities.

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